

SECTION 34 21 21
TRANSFORMER-RECTIFIER UNITS

PART 1 – GENERAL

1.01 SECTION INCLUDES:

- A. General
- B. Overload requirements
- C. Ratings
- D. Rectifier Transformers
- E. Rectifiers
- F. Factory testing
- G. Field inspection testing

1.02 MEASUREMENT AND PAYMENT

Not used.

1.03 REFERENCES

American National Standards Institute (ANSI)

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| ANSI B.1.1 | Unified Screw Threads |
| ANSI C2 | National Electrical Safety Code |
| ANSI C29.1 | Test Methods for Electrical Power Insulators |
| ANSI C39.1 | Requirements for Electrical Analog Indicating Instruments |
| ANSI C29.7 | Wet Process-Porcelain Insulators High-Voltage Line – Post Type |
| ANSI C29.9 | Wet-Process Porcelain Insulators (Apparatus, Post Type) |
| ANSI C34.2 | Practices and Requirements for Semiconductor Power Rectifiers |
| ANSI C37.2 | Electric Power System Device Function Numbers and Contact Designations |
| ANSI C37.20.1 | Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear |

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| ANSI C37.20.2 | Metal-Clad and Station-Type Cubicle Switchgear (above 1000V) |
| ANSI C37.41 | Standard Design Tests for High Voltage Fuses, Distribution Enclosed Single Pole Air Switches, Fuse Disconnecting Switches, and Accessories |
| <i>ANSI C37.45</i> | <i>Specifications for High-Voltage Distribution Class Enclosed Single-Pole Air Switches with Rated Voltages from 1 kV through 8.3 kV</i> |
| ANSI C37.90 | Standard for Relays and Relay Systems Associated with Electric Power Apparatus |
| ANSI C39.1 | Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus |
| ANSI C57.12.00 | Standard for Standard General Requirements for Liquid-Immersed Distribution Power & Regulating Transformers |
| ANSI C57.12.10 | Safety Requirements 230 kV and Below 833/958 Through 8,333/10,417 kVA, Single-Phase, and 750/860 Through 60,000/80,000/100,000 kVA, Three-Phase Without Load Tap Changing; and 3,750/4,687 Through 60,000/80,000/100,000 kVA with Load Tap Changing – Safety Requirements |
| ANSI C57.12.70 | Standard Terminal Markings and Connections for Distribution and Power Transformers |
| ANSI C57.12.80 | Standard Terminology for Power and Distribution Transformers |
| ANSI C57.12.90 | Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers |
| ANSI C57.13 | Standard Requirements for Instrument Transformers |
| ANSI C57.18.10 | Standard Practices and Requirements for Semiconductor Power Rectifier Transformers |
| ANSI C57.19.00 | Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings |
| ANSI C57.91 | Guide for Loading Mineral-Oil Immersed Transformers |
| ANSI C57.92 | Guide for Loading Mineral-Oil-Immersed Power Transformers up to and including 100 MVA with 55 degrees C or 65 degrees C Average Winding Rise |
| ANSI C57.93 | Guide for Installation of Liquid-Immersed Power Transformers |
| ANSI C57.98 | Guide for Transformer Impulse Tests |

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| ANSI C57.104 | Guide for Interpretation of Gases Generated in Oil-filled Transformers |
| ANSI C57.106 | Guide for Acceptance and Maintenance of Insulating Oil in Equipment |
| ANSI C57.109 | Guide for Liquid-Immersed Transformer Through-Fault Current duration |
| ANSI C57.110 | Recommended Practice for Establishing Transformer Capability When Supplying Non-sinusoidal Load Currents |
| ANSI C57.113 | Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors |
| ANSI C57.120 | Loss Evaluation Guide for Power Transformers and Reactors |
| ANSI C62.11 | Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits (1 > kV) |
| ANSI C62.22 | Guide for the Application of Metal Oxide Surge Arresters for Alternating Current Systems |
| ANSI Z55 | Standard Grey Finishes for Industrial Apparatus and Equipment |

American Society for Testing and Materials (ASTM):

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| ASTM D1275 | Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils |
| ASTM D2945 | Standard Test Method for Gas Content of Insulating Oils |
| ASTM D3487 | Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus |
| ASTM D6871 | Standard Specification for Natural (Vegetable Oil) Ester Fluids used in Electrical Apparatus. |

Institute of Electrical and Electronics Engineers (IEEE):

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| IEEE 4 | Standard Techniques for High Voltage Testing |
| IEEE 48 | Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV Through 765 kV |
| IEEE 100 | The Authoritative Dictionary of IEEE Standards Terms |
| IEEE 519 | IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power System |
| IEEE 693 | Recommended Practices for Seismic Design of Substations |

National Electrical Contractor's Association (NECA):

NEIS National Electrical Installation Standards

National Electrical Manufacturers' Association (NEMA):

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| NEAM BU 1 | Busways |
| NEMA EI 21.2 | Instrument Transformers for Revenue Metering (125 kV BIL Through 350 kV BIL) |
| NEMA ICS 4 | Industrial Control and Systems: Terminal Blocks |
| NEMA ICS 6 | Industrial Control and Systems: Enclosures |
| NEMA LA 1 | Surge Arresters |
| NEMA TR 1 | Transformers, Regulators and Reactors |
| NEMA WC 70 | Nonshielded Power Cables Rated 2000 Volts or Less for the Distribution of Electrical Energy. |
| NEMA RI-9 | Silicon Rectifier Units for Transportation Power Supplies |
| NEMA 250 | Guidance for Equipment Enclosures |

National Fire Protection Association (NFPA):

NFPA 70 National Electrical Code (NEC)

Electronic Industries Association (EIA):

EIA RS-282 Standards for Silicon Rectifier Diodes and Stacks

1.04 SUBMITTALS

- A. General: Refer to Section 01 33 00, Submittal Procedures, and Section 01 33 23, Shop Drawings, Product Data, and Samples for submittal requirements and procedures.
- B. Product Data: Submit product data to include the following:
 - 1. Physical arrangement and assembly of parts
 - 2. Wiring connections
 - 3. Schematic drawings
 - 4. Brief description of devices and their functions and special features.
 - 5. Equipment nameplate
 - 6. Transformer data including rated kVA, frequency, primary and secondary voltages, percent taps, polarity, impedance and certification of transformer

performance efficiency at indicated loads, percentage regulation at 100 percent and 80 percent power factor, no-load and full load losses in watts, percent impedance at 75 Degrees Celsius, hot-spot and average temperature rise above 40 Degrees Celsius ambient temperature, sound level in decibels, and standard published data.

- C. Operations and Maintenance Manuals. Submit operation and maintenance manuals complying with the requirements of Section 01 78 23, Operation and Maintenance Data.
- D. Test Reports. Submit reports of tests performed on the transformer-rectifier units.
- E. Installation Manual. Submit manufacturer's recommended installation procedures for the rectifier-transformers.

1.05 QUALITY ASSURANCE AND SUPPLIER QUALIFICATIONS

- A. Electrical components, devices, and accessories shall be listed and labeled in conformance with NFPA 70, Article 100. Electrical components, devices, and accessories and their installation shall comply with NECA's National Electrical Installation Standards (NEIS).
- B. Transformers and rectifiers shall be proven standard products, or equivalent to the standard products of manufacturers engaged in the production of such equipment for at least the past five years.
- C. The manufacturer of the rectifier transformers must have a minimum of five years manufacturing experience with three winding, liquid filled power transformers, utilizing ANSI C34.2 Circuit 31 configurations.
- D. The Engineer responsible for the design of the rectifier transformers and rectifier must have a minimum of five years of project-proven experience in the design of three-winding rectifier transformers.

1.06 DELIVERY, STORAGE AND HANDLING

- A. Delivery, loading/unloading, handling, storage and protection of transformer shall be in accordance with manufacturer's guidelines.
- B. All equipment shall be packaged for arrival at the site undamaged by handling and weather.
 - 1. Temporary braces, guides, skids, crates and other shipping devices necessary for transporting and temporary storage of the equipment shall be furnished.
 - 2. Equipment shall be protected against corrosion, dampness, damage due to vibration, and any other damage during transportation and handling. All opening to the external environment shall be sealed before shipping. Products shall be packed in weatherproof containers for storage outdoors.

1.07 WARRANTY

- A. A warranty for the rectifier transformers, traction rectifiers, and associated system components shall be provided and signed by the manufacturer and installer agreeing to correct system deficiencies and replace components that fail in materials or workmanship. The warranty shall be for the period between installation and the start of revenue service, five years from the date of system in revenue service for rectifier transformers and components, two years from the date of system in revenue service of traction rectifiers and components.

PART 2 – PRODUCTS

2.01 GENERAL

- A. Manufacturer shall coordinate the requirements of all associated substation equipment to provide a 1000V dc traction power supply.
- B. Transformer windings, rectifier buses and interconnecting AC buses shall be made of copper conductors.
- C. The transformer/rectifier units shall be designed and fabricated in accordance with the latest revision of the applicable ANSI and NEMA Standards as listed in Section 1.03.
- D. Each unit shall consist of a rectifier transformer and a traction rectifier with all necessary hardware, wiring, and devices as indicated, and as required for a complete and operating installation.
- E. The rectifier transformer will receive 34.5 kV, 3-phase, 60 Hz, 3-wire power from 34.5 kV switchgear and shall transform the high voltage to a low ac voltage rated as required by the traction rectifier.
- F. The traction rectifier will receive the low voltage ac power from the secondary winding of the rectifier transformer and convert the ac voltage to nominal 1000 V dc output power of the rectifier supplies the dc switchgear.
- G. The rectifier transformer and traction rectifier shall be designed for interconnection by aerial ac busway, as indicated. Connections between the rectifier and the dc switchgear may be by either dc cables or bus, depending on the rectifier and switchgear design.
- H. Transformer windings, rectifier buses and interconnecting AC buses shall be made of copper conductors.
- I. The transformer/rectifier units shall be designed and fabricated in accordance with the applicable ANSI and NEMA standards.
- J. In lieu of the warranty period duration required in the General Conditions GC 4.9, the warranty period for the rectifier transformers shall be five years.

2.02 OVERLOAD REQUIREMENTS

- A. The transformer-rectifier unit shall be rated for extra heavy-duty traction load. The unit shall be able to operate at the following overload cycle, beginning from operation at nominal load and stabilized temperature:
 - 1. One hundred and fifty percent of rated current for two hours, with superimposed five periods of one-minute duration at 300 percent of rated current each, equally spaced throughout the two-hour period, and
 - 2. Four hundred and fifty percent of rated current for 15 seconds at the end of the two-hour period.
- B. The transformer-rectifier unit shall withstand two overload periods as specified above on a daily basis, spaced eight hours apart, each preceded and followed by the continuous 100 percent load level.
- C. The transformer-rectifier units shall be designed to meet the above daily duty cycle without damage to any parts or the insulation for a period of 25 years.
- D. Current unbalance caused by loss of one diode per phase shall be taken into consideration in the design, and shall not reduce the specified overload capability of the rectifier.

2.03 RATINGS

- A. Unit Capacity
 - 1. The KW rating of the transformer-rectifier units shall be as indicated. The units shall be designed to deliver the rated KW output at rated terminal voltage.
 - 2. The units shall withstand continuous operation at 110 percent rated voltage without exceeding the equipment temperature limitations.
- B. Efficiency: The overall efficiency of the transformer-rectifier shall be greater than 97.5 percent at its continuous rating. No-load core losses shall not exceed 0.25 percent of the rated unit capacity.
- C. Power Factor: The displacement power factor of the transformer-rectifier units shall be 0.95 or greater from 25 percent to full load with rated ac input voltage.
- D. Voltage Regulation: The transformer-rectifier units' initial regulation shall be six percent. The regulation shall be linear from light transition (one percent) load to at least 300 percent of full load. Manufacturing tolerance shall not exceed 10 percent of the specified regulation value. The voltage at the rectifier output at no-load shall not exceed 1100 V dc at rated primary voltage of 34.5 kV. The light transition load voltage shall be approximately 1,060 volts dc at the rated primary voltage of 34.5 kV, while the full-load (nominal) voltage shall be 1000 V dc, with plus-or-minus 6 V maximum deviation allowed for manufacturing tolerance.

E. Short-Circuit

1. Each transformer shall be designed to withstand a full short-circuit at the low-voltage terminals at rated voltage on the high-voltage terminals for one second, in accordance with ANSI C57.12.00 and C57.12.10.
2. All parts of the rectifier unit, including the terminal connections and buswork, shall be designed to withstand a bolted fault on the dc positive bus, without damage, for the time period required for the backup protection to operate and open the ac circuit breaker.
3. The transformer shall be designed to withstand the short-circuit power available from the 34.5 kV subtransmission lines at the switching stations which is expected to be up to 500 MVA.
4. The secondary windings of the rectifier transformer shall be coupled magnetically, so that at a given fault level of 500 MVA at 34.5 kV, the sustained short circuit current on the rectifier bus for a bolted fault does not exceed nine times the full load current.

F. Additional Rating Requirements:

See Section 2.04 for rectifier transformer ratings.

G. Voltage Transients

1. A plan of the design techniques, construction methods, and equipment employed to protect against transient surge voltages shall be submitted for approval.
2. If fuses are used in surge suppression networks, they shall be monitored by visual indicators, and shall be equipped with devices capable of being monitored by a local annunciator.
3. A surge protection network at the input terminals shall protect each rectifier unit from damage due to switching voltage transients up to two and a half times normal voltages in the 34.5 kV ac system. Failure of the surge protection network shall be annunciated as indicated.
4. A static voltage surge suppressor rated to withstand expected voltage transients, shall protect each rectifier from lightning surges transmitted along dc contact rails, and from voltage transients on the dc system due to breaker switching. A counter shall be provided for the surge suppressor. Failure of the surge suppressor shall be annunciated.
5. The surge suppressor shall absorb surge energy of 50 kilojoules minimum with bus potential below 2600 volts at instantaneous current of 4000 amperes.
6. The peak value of contact rail transient voltages is expected to be 3000 volts for eight milliseconds or 6000 volts for 50 microseconds with rise time of 1.2 microseconds.

H. Noise Levels

1. Equipment design, enclosures with acoustic mitigation capability, and other measures, as appropriate, shall be employed to achieve compliance with the specified audible noise level criteria.
2. The noise level measured at a distance of 15 feet from the rectifier transformer with the transformer operating at 100 percent load and nominal voltage shall not exceed 55 dBA.
3. The noise level measured at a distance of five feet from the rectifier with the rectifier operating at 100 percent load and nominal voltage shall not exceed 60 dBA.
4. Submit proof in the form of calculations or empirical data that the rectifier transformer meets the noise level requirements.

2.04 RECTIFIER TRANSFORMERS

A. General

1. Rectifier transformer shall be self-cooled, oil-immersed, 60 Hertz transformers suitable for outdoor service, designed for extra heavy duty traction service as specified, conforming to the applicable requirements of ANSI C57.12.00, ANSI C57.12.10, ANSI C57.12.90, ANSI C57.18.10, and NEMA TR-1. The rectifier transformers shall be suitable for operation on 34.5 kV line-to-line, effectively grounded neutral system.

B. Ratings: Rectifier Transformers shall have the following minimum ratings:

1. Capacity: MVA rating as required to meet the specified ratings and performance requirements for the Transformer-Rectifier Units.
2. Primary Winding Nominal Voltage: 34.5 kV
3. Secondary Winding Nominal Voltage: As required to meet the specified performance requirements for the Transformer-Rectifier Units.
4. Frequency: 60 Hz
5. No. of Phases: Primary – 3 Secondary – 6
6. Cooling Class: KNAN
7. Average Winding Temperature Rise above 50 Degrees Celsius ambient after stabilized continuous operation at 100 percent load: Fifty-five Degrees Celsius maximum.
8. Hottest-Spot Temperature Rise above 50 Degrees Celsius ambient after stabilized continuous operation at 100 percent load: Sixty-five Degrees Celsius maximum.

9. Basic Insulation Level (BIL) peak:

- a. Primary Winding: 200 kV minimum
- b. Secondary Windings: 45 kV minimum

10. Connections:

- a. Primary Winding: Delta
- b. Secondary Windings: Delta/Wye for the two six-pulse double-way rectifiers in accordance with ANSI C34.2, circuit number 31.

11. Bushings: Rated voltage and BIL peak ratings not less than winding ratings.

C. Taps and Tap Changer:

- 1. Taps: The high voltage winding shall have four no-load, full-capacity taps: two that are two and a half percent above, and two that are two and a half percent below the rated line-to-line voltage of 34.5 kV.
- 2. Changer: An off-load tap changer shall be provided with an operating handle mounted on the exterior of the tank. A position indicator and provision for padlocking shall be provided in an accessible location.

D. Alarm and Trip Devices: Transformer shall be equipped with the following:

- 1. Sudden pressure relay with alarm and trip contacts.
- 2. Pressure relief device.
- 3. Liquid level gauge with two low-level alarm contacts.
- 4. Pressure/vacuum gauge.
- 5. Two stage top oil temperature indicator with alarm and trip contacts with adjustable temperature set points.
- 6. Hot-spot winding temperature indicator, minimum two stages, with alarm and trip contacts with adjustable temperature set points.

E. Heaters

- 1. The main transformer control cabinet shall have non-thermostatically controlled anti-condensation heaters.
- 2. Heater capacity shall be equally divided into two and located at the sides of the cabinet to maintain adequate clearances from entering cables.

F. Construction Requirements

1. The rectifier transformers shall be designed for high voltage cable connections on the primary side and throat connection accommodating aerial busway to the rectifier.
2. Transformers shall be provided with lifting lugs located at the top of the unit in such a manner to allow the unit to be lifted by a boom-type crane or hoist without tilting of the unit.
3. The transformer shall be designed for mounting on a concrete pad.
4. The transformer tank shall be a sealed tank liquid preservation system.
5. The transformer shall include the following additional requirements:
 - a. Top filter press connection and sampling device.
 - b. Tank bottom drain valve and sampling device.
 - c. Gasketed, roof-mounted inspection covers to gain access to internal devices or connections.
 - d. Nameplate with connection diagram.
 - e. Warning signs as required.
 - f. Weatherproof, oversize connection box with provision for extension throat and access to end or side, removable for termination of low-voltage cables.
 - g. Top mounted bushings
6. Transformer Tank
 - a. The tank shall be mounted on a structural steel base that is adequate to provide support for the completely assembled transformer filled with oil and to prevent distortion during operation or relocation. Internal bracing shall not interfere with oil drainage. The structural steel base shall consist of at least two members parallel to the transformer major axis and at least two members parallel to the minor axis. The undersides of all members shall be in the same plane. The spacing of the base member shall be such as to permit the completely assembled transformer with or without oil to be safely tilted 15 degrees.
 - b. Transformers shall be of the sealed tank, welded steel plate and cover construction, outdoor type, liquid tight, with bolted and gasketed manhole(s) on top of tank. They shall be mounted on steel skid base, suitable for skidding in any direction. Use care to avoid tank or component distortion during welding operations. Assembled transformer base shall be sufficiently flat to be installed on a flat concrete foundation without supplemental shims. They shall be adequately designed and braced to allow full vacuum filling and vacuum drying operations in the field.
 - c. Provide jacking lugs and pulling eyes for lifting or moving along either axis when completely assembled and oil-filled. Lifting lugs are to be mounted

near the top of the tank. Jacking lugs shall be installed with suitable clearance to the bottom of the base plate.

- d. Provide two NEMA two-hole copper faced or stainless steel ground pads at diagonal opposite corners of transformer tank near base, with two-bolt terminal connectors for 250 kcmil copper conductors.
- e. Maintain positive pressure continually to prevent ingress of moisture during shipping.
- f. Provide an adequately braced domed or sloped top on all major surfaces. Design tank and fittings to prevent water puddling on surfaces or in cavities.
- g. Provide raised flanges with thru-bolts for all removable cover penetrations, including bushings, manhole/handhole covers and removable equipment. Welded studs are not acceptable.
- h. All Gasketed joints shall have machined surfaces on both sides and shall be provided with gasket retainers and metal-to-metal stops to assure even the effective pressure and to avoid over-stressing the gasket. Gaskets shall maintain oil-tight joints under all service and fault conditions.

7. Core

- a. Each core shall be fabricated from non-aging, cold-rolled, grain-oriented, stress-free, thin silicon steel laminations, with permeability and hysteresis loss characteristics necessary to satisfy design and performance requirements.
- b. Provide each sheet with an insulated surface treatment which is impervious to hot transformer oil. Anneal properly with smooth surfaces at edges.
- c. Core shall be rigidly clamped and blocked to prevent deteriorating vibrations, interference with oil circulation, objectionable noise conditions and short circuit and shipment distortions.
- d. Provide a core ground lead connected to an external bushing for each core. Provide a flexible ground strap to connect the terminal of the bushing to the transformer tank, thereby grounding the transformer core. Provide a suitable cover or deflector to protect the core ground bushing from damage from falling objects. Provide an engraved nameplate clearly indicating the function of the bushing. Provide a separate core ground bushing and ground strap for each separate core.
- e. Serial number shall be stamped on core or core clamp in conspicuous place and shall be visible without the necessity for untanking or otherwise removing entire enclosure.
- f. Provide means for properly handling core assembly when untanked.

8. Windings

- a. The windings shall be of copper and have insulation of high dielectric and mechanical strength and shall be arranged to permit free circulation of oil.

Proper internal barriers shall be provided. Additional insulation shall be provided on end coils to protect against line disturbances.

- b. The coils shall be made up, shaped and braced to provide for expansion and contraction due to temperature changes and to avoid abrasion of insulation. The coils shall be braced to prevent distortion due to any abnormal operating conditions, and designed to withstand short circuit conditions in accordance with IEEE C57.12.90.
- c. Each lead for connection to tap changers, bushings, etc. shall be permanently identified.

9. Radiators

- a. Radiators shall be detachable. The transformer cooling radiators shall be equipped with shut-off valves top and bottom and shall be bolted to the main tank to facilitate removal from the transformer main tank. The transformer shall be shipped with the radiators on at least one side removed to allow for the use of a standard size trailer, if necessary. The oil required to fill the removed radiators shall be shipped with the transformer or be provided by a local supplier.
- b. All shutoff valves shall be equipped with a valve position indicator to indicate "valve open" or "valve closed". The valves shall be lockable in the open and closed position. Steel blanking plates for all openings shall be supplied.
- c. Each radiator shall have a solid Hexsteel plug provided at the top and ball type drain valves at the bottom for drainage.
- d. Each removable radiator shall be equipped with one lifting lug on top and one lifting lug on the bottom.
- e. The design and construction of the radiators shall be such as to eliminate pockets where moisture can accumulate or which can prevent application of a continuous film of paint. Radiators shall be either hot dipped galvanized or painted in a fashion which ensures complete coverage of all radiator surfaces. The radiators shall be provided with adequate bracing to prevent leakage from vibration.
- f. Radiators are to have the same vacuum capability as the main tank.

10. Transformer Oil

- a. The transformer shall be provided with sufficient amount of transformer oil for filling its tank and radiators to the proper level.
- b. Transformer oil shall be natural ester-based insulating fluid which provides for a low-vapor-pressure, low-viscosity, high-flash-point, stable insulating oil.
- c. Supplier shall certify, 60 days before delivery that oil used in rectifier transformers contain less than one ppm PCB at time of manufacture.
- d. The oil shall be Environtemp FR3 or approved equivalent.

G. Special Tools

1. All special tools required for installation and maintenance of the equipment shall be identified by the manufacturer at time of bid.

H. Marking

1. Every transformer shall be provided with a rating plate showing all the information required by the applicable ANSI Standard.
2. The rating plate shall indicate the type of conductor used for both high voltage and low voltage windings; i.e. copper.
3. The rating plate shall indicate the transformer is constructed for Extra-Heavy Traction Duty as defined in IEEE C57.18.10.
4. The transformer shall be provided with nameplate which reads:
5. "Transformer oil contains less than two parts per million polychlorinated biphenyls at time of shipment." and "Refill with Envirotemp FR3 or approved equivalent

2.05 RECTIFIERS:

A. General

1. Each rectifier bridge or section shall be a complete self-contained unit consisting of silicon diodes, heat sinks, protective fuses, natural ventilation system, copper buses and bus connections, enclosure with doors, hardware, gaskets, and all other necessary accessories and devices.
2. The rectifier shall be the indoor type, with natural convection-cooling, and shall be designed to operate at 50 degrees Celsius ambient temperature.
3. The rectifier shall consist of two six-pulse, delta-wye, double-way circuits each having six legs of diode devices, per ANSI C34.2 circuit No. 31.
4. An interphase transformer shall be provided between the direct outputs of the two six-pulse sections to absorb the instantaneous direct voltage differences. To achieve the lowest practical noise level, the core of the interphase transformers shall be designed to minimize the magnetostriction. Magnetostriction is the phenomenon of elastic deformation that accompanies magnetization. Noise damping treatment may be required in reducing the noise level by canceling some of the noise frequencies of the interphase transformer. The Contractor shall submit calculations showing that the noise level expected for the transformer under full load or maximum excitation meets the specified noise level limits for the transformer-rectifier unit per Article 2.03H of this Specifications Section. The calculations shall be signed by a California registered engineer specialized in noise suppression field.
5. Materials shall be chosen to preclude the possibility of corrosive or galvanic action between dissimilar metals. Compatible materials shall be used for diode cases, studs, and heat sinks.

6. The rectifier enclosures shall be designed for high-resistance type enclosure-to-ground protective relaying.

B. Rectifier Enclosures

1. All panels comprising the rectifier enclosure including doors shall be constructed of sheet steel, not less than No. 11 gauge, and mounted on rigid, self-supporting structural steel framework.
2. Glastic type insulation shall be provided between the rectifier and dc switchgear, and between the rectifier and the negative return cabinet. Also, adequate electrical insulation shall be provided between the rectifier enclosure and the ac busway from the rectifier transformer.
3. Louvered or mesh openings shall provide ventilation and air-cooling of the components by natural convection.
4. Ventilation intake openings shall be located not less than six inches above the floor.
5. Heat transfer surfaces and ducts shall be designed with smooth surfaces that minimize accumulation of dust and other contaminants.
6. Convenient access, including doors on both front and rear sides, shall be provided for all normal maintenance and inspection of the rectifier.
7. Each enclosure door shall be equipped with:
 - a. a mechanical latch to hold the door closed and
 - b. door stops to hold door open for inspection of rectifier components.
8. Openings and mounting holes for front mounted indicating and control devices shall be cut out, drilled, or punched without marring or distorting the exposed finished surfaces of the control cubicles.
9. Rectifier enclosure shall be furnished with viewing windows so that blown-fuse indicators and the position of the negative disconnect switch can be seen from the outside, without opening the rectifier doors.
10. Separate compartments shall be provided to isolate control and auxiliary circuits and functions from the 1000 V dc buses and diodes.
11. All readings, controls, and observations shall be made without exposure to live parts. Internal lights with an external switch shall be included. Lighting fixtures shall be provided with guards.
12. All components installed in the rectifier shall be capable of withstanding 4600 V dc for one minute, applied between completely assembled rectifier and ground, with control circuits connected and energized or grounded, except that ground connection to the 164A/164G relay shall be disconnected and its contact set in the OPERATE (tripped) condition.

13. The enclosure shall be connected to the high resistance ground relay (Device 164A/164G) in the associated DC switchgear.

C. Diodes

1. Diodes shall be rated and tested in accordance with EIA RS-282. Parallel strings of diodes shall be geometrically similar and as symmetrical as practicable to balance the normal and surge electrical characteristics of each string.
2. In addition to the parallel strings necessary to handle all loads, as specified, additional capacity shall be provided so that, with one diode per phase leg out of service, each current path will still handle all specified loads and maximum short circuit current.
3. Each diode shall be able to withstand, at its maximum operating temperature, voltages two and a half times higher than the no-load ac bus voltage of the rectifier, without a permanent change in diode characteristics.
4. The maximum current unbalance between parallel strings in each phase and between phases shall be such that removal of any one diode per phase does not impact the required thermal capacity or short-circuit withstand capability of the rectifier.
5. Each parallel diode string shall be protected against internal short circuits by a current-limiting, fast-acting fuse equipped with a microswitch for remote status indication, and visible blown-fuse indicator.
6. Diodes shall have uniform voltage division within plus or minus ten percent across each diode.
7. Each parallel diode string shall be protected by a current-limiting fuse equipped with an indicator. The fuses shall be sized to withstand any external dc fault or loading condition. The fuses shall blow to clear any failure permitting reverse conduction. A blown fuse indicator shall be visible from outside the rectifier enclosure. Alternative to fuses shall require District approval.
8. The number of diodes per leg shall not exceed 10 for 3-MW and 4-MW units, and 12 for 5-MW units, unless otherwise approved by the District.

D. Terminations

1. The rectifier shall be connected to its associated rectifier transformer through a metal enclosed busway, as indicated.
2. The rectifier dc output shall be connected either through a metal-enclosed positive bus or cables to its associated 1000 V dc switchgear.
3. The throat connections between equipment and busways shall be designed for close coupling and for installation and removal without the necessity of moving the transformer, rectifier, or dc switchgear.

4. Flanges shall be provided with gaskets to prevent entrance of moisture.
5. The negative dc terminal of each rectifier section shall be bus-connected to the negative disconnect switch through a metering shunt.

E. Negative Disconnect Switch

1. The rectifier shall be furnished with a negative disconnect switch, which shall be:
 - a. No-load, single-pole, single-throw, non-ferrous, non-magnetic, with solid copper current-carrying parts and silver-plated contacts. The switch shall be manually operated, bolted-pressure type, rated for at least 600 V dc nominal, and with current ratings matching the overload and short-circuit capability of the rectifier;
 - b. Provided at a minimum with one normally-open and one normally-closed auxiliary contact;
 - c. Designed with ample space and contact surface for pulling and terminating the negative cables from the negative bus enclosure; and
 - d. Key-interlocked with the associated main dc circuit breaker, so that the switch can be operated only with the main breaker in the open and withdrawn position.
 - e. Equipped with insulated handle.
2. NEMA 2-hole, 750 kcmil standard connectors shall be furnished for the cable terminations as indicated.
3. A viewing window shall permit inspection of the disconnect switch position without opening the rectifier compartment.

F. Relaying, Metering and Indicating Devices

1. Relaying, metering, and indicating devices shall be provided as indicated.
2. Temperature-measuring Devices (126DT) shall be installed to detect an abnormal rise in diode heat sink temperatures. Each device shall have at least two stages. First stage contact shall be for annunciation and the second stage for breaker tripping. The pickup point of each stage shall be adjustable and factory-set so that upon the heat sink temperature reaching the preset level the corresponding contact shall initiate an alarm or trip the station circuit breakers through the lockout relay (Dev 286) as indicated.
3. Monitoring Devices (180DM) shall be furnished to detect the loss of one or more diodes:
 - a. Failure of any diode in any string shall initiate an alarm.
 - b. Failure of a second diode in a rectifier bridge shall initiate the tripping of the substation circuit breakers via a lockout relay (Dev 286).

- c. Rectifier doors to normally energized buses or components and to the negative disconnect switch shall be electrically interlocked to trip the ac and dc main circuit breakers through the lockout relay (Device 286), when a door is opened.

PART 3 – EXECUTION

3.01 FACTORY TESTING

- A. General: Testing shall be performed in accordance with the requirements specified in Section 01 45 24, Testing Program Requirements.
- B. Transformer / Rectifier Units
 - 1. The following design tests shall be performed on one transformer/rectifier unit complete with the 34.5 kV ac circuit breaker, the bus connecting the rectifier transformer to the rectifier, and the accessories. Unless specified otherwise the tests shall be performed with all equipment fully assembled including the enclosures.
 - a. Basic Performance Parameters. Design tests shall be performed to verify the efficiency, voltage regulation, displacement power factor, and diode current balance at loads of 0, 25, 50, 75, 100, 150, 300 and 450 percent of rated load.
 - b. Temperature Rise Test
 - 1) Contractor shall locate the temperature probes in accordance with the industry standards, and use the test results from the individual probes to calculate the expected temperature rise on all components of the involved equipment, and to verify that local temperatures of the transformer, the rectifier and busway are within the limits indicated in ANSI C34.2, ANSI C37.20.1, ANSI C37.20.2, ANSI C57.18, and NEMA RI-9.
 - 2) The transformer/rectifier units shall be operated at 100 percent full-load till all parts have reached constant temperature before applying overloads. Constant temperature is deemed to be reached if the temperature rise change of any part becomes less than one degree Celsius per hour.
 - 3) After constant temperature has been reached, the transformer/rectifier unit shall be operated at 150 percent full load for two hours with five cycles of 300 percent full load for one minute duration, each equally spaced throughout the two-hour period, followed by one period of 450 percent full load for 15 seconds at the end of the two-hour period.
 - 4) The temperature rise tests may be performed with shorted rectifier output terminals, and at reduced ac input voltage sufficient to produce the required load currents.
 - c. Short-Circuit Test
 - 1) Bolted short-circuit fault shall be made on the output terminals of the rectifier to verify the capability of the equipment to withstand the

maximum fault current without damage. The source shall be 3-phase, 34.5 kV ac, with fault level of no less than 500 MVA.

- 2) The fault shall be cleared by the ac circuit breaker's 251B backup overcurrent relay, set the same as it will be on the installed system.
- 3) Each phase of the ac circuit breaker and the output of the rectifier shall be monitored. Test results of voltages and currents as a function of time shall be recorded on an oscillograph.

d. Noise Level Tests

- 1) Noise level tests shall be performed on one transformer/rectifier unit including the interphase transformer mounted in its permanent location.
- 2) The noise level at full load, measured in accordance with NEMA TR1 and ANSI C57.12.90, shall not exceed the specified levels.

- e. Tests to establish the transformer-rectifier unit efficiency, voltage regulation, and power factor at 0, 1, 25, 50, 75, 100, 150, 200 and 300 percent of rated load. The tests shall be used to determine the required parameters by direct measurement; or, where direct measurement is not possible, the Contractor shall conduct tests to obtain data for the indirect derivation of the required parameters via calculations.

2. Production Tests – All production tests shall be performed per ANSI requirements.

C. Rectifier Transformers

1. The following design tests listed in ANSI C57.12.90, C57.18, ANSI C34.2 and NEMA TR1 shall be performed on one rectifier transformer of each size:
 - a. Dielectric tests – impulse tests. Tests shall include one application of a reduced full-wave, two applications of a chopped wave, followed by one application of a full-wave. These tests shall be performed after the short-circuit tests and temperature rise tests on the rectifier transformer.
 - b. Audible noise test as in NEMA TR1 and ANSI C57.12.90
 - c. Impedance and load loss at rated current on the rated voltage connections and on all taps.
 - d. Commutating reactance and resistance per ANSI C34.2
 - e. Short-circuit tests, as described in ANSI C57.12.00 and ANSI C57.12.90, shall be performed to evaluate fully the capability of all windings. At least one extreme of the tap range shall be used in the tests. Short-circuits shall be applied on the secondary terminals of each winding.
2. The following production tests shall be performed on all rectifier transformers in accordance with ANSI C57.18 and NEMA RI-9:
 - a. Resistance and impedance measurements including zero sequence impedance of all windings on the rated voltage connection of each unit and at all taps.

- b. Ratio tests at the rated voltage on all tap changer connections.
 - c. Phase-rotation tests on the neutral tap connection.
 - d. No-load loss at rated voltage on the neutral tap connection.
 - e. Excitation current at rated voltage on the neutral tap connection.
 - f. Dielectric tests – low frequency withstand, including applied and induced potential tests.
 - g. Load losses and impedance voltage at rated current on the rated voltage connections and on all taps.
 - h. Partial-discharge tests: The partial discharge test shall be in accordance with ANSI C57.12.01 and IEEE C57.124, and shall be used to verify that the transformer insulation is free of partial discharges for voltages up to 120 percent of the rated primary voltage.
3. Pre-Energization Field Inspection Testing – In addition to requirements of Section 34 21 80, Traction Power Field Acceptance Testing, perform the following
- a. Visual inspection of transformer to verify that there is no damage to the transformer or its accessories
 - b. Verification of the ground grid resistance.
 - c. Removal of CT shorting links, if installed.
 - d. Measurement of winding resistance at all taps and comparison with the factory test values.
 - e. Insulation power factor

D. Rectifiers

- 1. Design tests shall be performed on one rectifier, including the diode protection, monitoring and alarm functions, in accordance with NEMA RI-9 and ANSI C34.2. Design tests shall also be performed on the negative disconnect switch in accordance with ANSI C37.45.
 - a. Diode types for use in the rectifier shall be fully tested in accordance with EIA RS-282. Results of these tests, including both routine and type tests shall be submitted to the District.
 - 1) Included in these reports shall be two copies of the Registration Format outlined in EIA RS-282.
 - 2) The test results shall be certified by both the diode manufacturer and the rectifier manufacturer.
 - b. End points for all tests shall be well beyond any maximum values to be expected under any loading conditions. Diodes shall be dated as specified using the four-digit code and shall meet or exceed Class B requirements in accordance with EIA RS-282.

- c. Rectifier-type instruments shall not be used in making any of the specified tests. In general, limiting or end point values for reverse current or forward voltage drop shall be at least twice the maximum rated values listed in the registration format. Each curve shall be clearly labeled to show test conditions and shall show actual data points.
- 2. The following production tests indicated in NEMA RI-9 and ANSI C34.2 shall be performed on all rectifier units:
 - a. Dielectric strength test.
 - b. Rated voltage test.
 - c. Rated current test, including current imbalance, with the latter:
 - 1) Between phases
 - 2) Between each diode in each phase
 - d. Diode protective, monitoring and alarm functions.
 - e. All applicable tests identified as Production Tests in ANSI C37.41 for the negative disconnect switch.

END OF SECTION 34 21 21